

Research on Information Control of Smart Control System Based on Wi-Fi Internet of Things

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Abstract. With the steady development of the social economy and rapid progress in science and technology, people have entered the era of digital network life. Both daily life and work fields have shown characteristics of intelligence and personalization. People can effectively control the power, lighting, and appliances in their environment by adding receiving and control ends. After understanding the current status of domestic and international research on intelligent home control systems and their design applications, this paper discusses the architecture of the intelligent control system based on Wi-Fi Internet of Things, analyzes the design of Wi-Fi wireless perception systems based on low-computing platforms, and combines practical applications for performance testing to prove the security and effectiveness of system information control.

Keywords: Wi-Fi; Internet of Things; Smart Home; Smart Control System; Low-Computing Platform.

1. Introduction

In the development of Internet of Things (IoT) technology, the analysis of widely existing wireless signals to target behavior has become a new type of IoT perception technology. The related applications of this technology are increasing and show advantages of intelligence and ubiquity, achieving excellent results in various fields such as intelligent driving, identity recognition, and human-computer interaction [1]. In the development of modern society, the human-computer interaction methods between citizens and smart home devices are becoming more diverse, such as gesture recognition, voice recognition, and brain interfaces, which promote more intelligent and convenient practical applications. To better meet the development requirements of human-computer interaction, it is usually necessary to collect and analyze basic information such as human movements and behaviors. Common perception methods are divided into two types: contact and non-contact [2]. Contact refers to the use of wearable special devices or sensors installed on human limbs and joints to obtain information such as the speed, angular velocity, and acceleration of human body movements, and to calculate the direction and speed of limb movements based on this information to construct corresponding physical models, thereby achieving the perception of specific actions; non-contact refers to images and videos, which usually use infrared or wireless signals and other technical means. Compared with contact perception modes, non-contact does not require users to wear any devices, so practical research applications are more convenient and can perform long-term and uninterrupted perception analysis [3]. Compared with the first two technologies, wireless perception technology is not affected by factors such as light and weather, has a larger actual perception range, stronger penetration, and can fully protect user privacy. Currently, there are more and more studies on human gesture action perception based on Wi-Fi signals, mainly focusing on improving the accuracy of action recognition and cross-scenario robustness, and less attention is paid to smart home scenarios.

From an international development perspective, traditional Wi-Fi modules have high power consumption and are not suitable for battery-powered smart devices. Therefore, some scholars [4] have proposed a low-power Wi-Fi direct connection protocol, which is mainly suitable for short-distance communication between smart sensors and home appliances, with power consumption only one-tenth of that of traditional Wi-Fi; some scholars [5] have considered that smart home appliances involve user privacy, so they use end-to-end encryption (E2EE) technology to ensure that control commands are not hijacked, or require all connected devices to pass hardware-level authentication to prevent malicious device intrusion; foreign enterprises are more inclined to establish unified standards to improve device compatibility, such as the Matter protocol (formerly CHIP), which is jointly launched by Apple, Google, Amazon, etc., and can support interconnection between devices of different brands, solving the fragmentation problem of smart homes. Some companies also try to run the Zigbee protocol on Wi-Fi networks, taking into account both low power consumption and high-speed transmission [6].

From a domestic development perspective, research on intelligent home control systems mainly focuses on protocol optimization, cloud collaboration, and AI empowerment, and the design of information control ends is gradually developing towards high integration, low latency, and strong security. For example, some scholars [7] have introduced lightweight MQTT communication based on existing Hilink protocols and Wi-Fi, reducing the communication latency of smart home appliances; some scholars [8] have built a collaborative architecture centered on cloud, edge, and end, deploying edge computing nodes on the information control end to reduce dependence on the cloud, shortening the local response time of home appliance control to within 50ms; some companies have also made significant breakthroughs in voice control and scene linkage, such as iFlytek's voice recognition technology, which has been widely used in smart home control ends, supporting multi-round dialogues and dialect recognition [9].

With the rapid development of IoT technology, the intelligent home control system based on Wi-Fi has become one of the core research directions in the field of smart homes. The information control end, as the core content of the system, is mainly responsible for device interconnection, data processing, and user interaction, and its performance directly affects the stability, response speed, and user experience of the system [10]. This paper starts from the current research status at home and abroad, analyzes the key technologies, application progress, and future trends of the information control end of the Wi-Fi IoT intelligent home control system, designs and uses a Wi-Fi wireless perception system based on a low-computing platform, thereby meeting the control needs of smart homes and providing technical support for the construction of smart cities.

2. Methodology

2.1 System Architecture

The information control architecture of the smart control system based on Wi-Fi networking studied in this paper is designed using the C/S model. During communication, the mobile client and the home system module can establish a reliable connection through the TCP protocol: first, a socket connection is established between the client and the module, and the home system module listens on the port for the client's connection; second, at the connected client port, a password must be entered, and only after the password is correct will the server side start a thread for client communication, save the socket connection to a vector, and establish input and output streams

between the two; finally, if the client wants to change the state of the home appliances, they only need to enter the control system, call the sendmethod to send a request to the server side, and after the port responds, change the state of the appliances, and finally return the result to the client. The client can obtain the changed status by calling the received method [11]. The working principle of the system is shown in Figure 1 below.

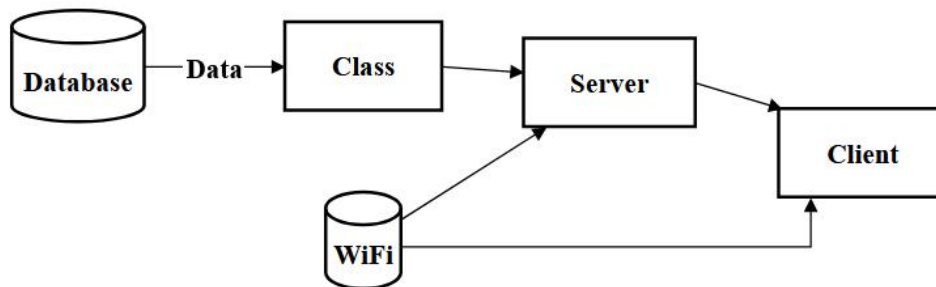


Figure 1 System Architecture Schematic Diagram. As shown in the analysis above, after the client completes primary functions, control information is transmitted to the server via Wi-Fi network, which then returns to the client, enabling effective control of home appliances. The information control system primarily consists of an information appliance controller and various smart remote switches. Through the Wi-Fi module of the ARM9 S3C2440 local central controller for home appliances, commands are processed through encoding and sent to the wireless gateway. The microprocessor on the appliance switch parses the received commands via wireless communication and activates relays to control appliance operations.

2.2 Wi-Fi Wireless Perception System Design

Based on Low-Computational-Power Platforms To address challenges such as high complexity in information control, a low-computational-power platform is adopted to design the smart home operation system. The overall architecture is shown in Figure 2, which is divided into three functional layers:

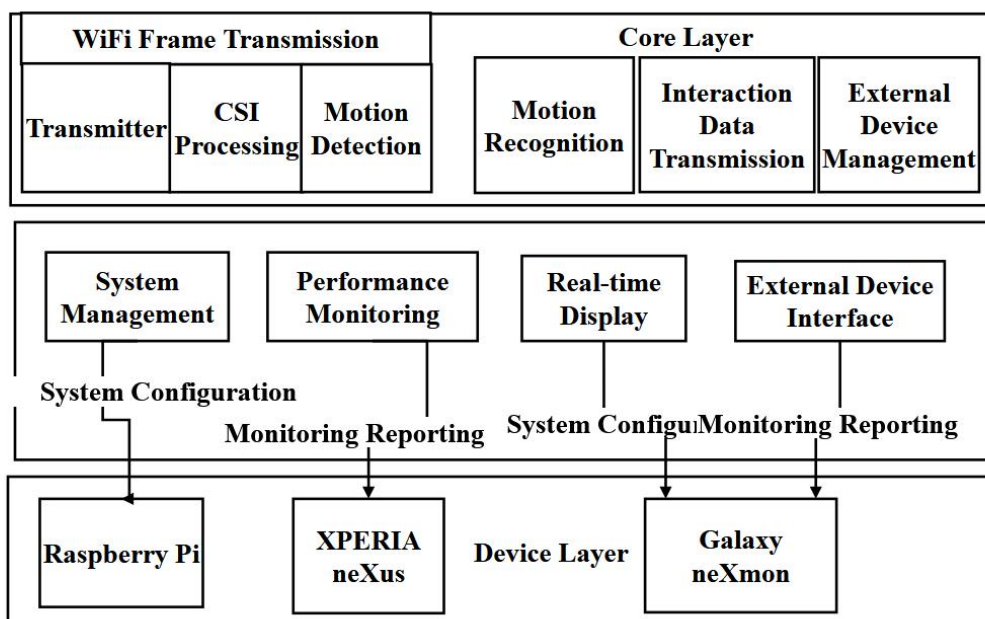


Figure 2 Architecture Diagram of Wi-Fi Wireless Perception System

Based on Low-Computing-Power Platforms. First, the Device Layer. This layer includes hardware devices and underlying support software required for system operation. Both transmitter and receiver units utilize low-power platforms with Linux kernels at their core, which simplifies device-level development and facilitates subsequent portability [12]. Second, the Core Layer. This layer contains implementation programs for core system functions in both transmitter and receiver units. Both devices feature system configuration modules and monitoring reporting modules. The configuration module acts as a proxy program that processes user configuration requests, executes corresponding scripts to adjust program parameters, and performs basic operations like shutdown, reboot, and startup. Meanwhile, the monitoring reporting module functions as a daemon that periodically collects operational status, resource usage, and other critical metrics, transmitting data to a monitoring database to ensure users can accurately access performance metrics through dedicated interfaces [13]. Finally, the Interaction Layer. This layer primarily handles interfaces between the system's core layer and users, typically implemented through two approaches: The first enables users to modify system parameters via web interfaces, scientifically control system startup/shutdown processes, monitor real-time operational data, and access collected information. The second exposes application programming interfaces (APIs) for external devices, providing an effective platform for gesture control interactions between users and peripherals [14].

2.3 Functional Module Analysis

The core layer incorporates multiple functional modules including Wi-Fi frame transmission, CSI acquisition, CSI preprocessing, motion detection, motion recognition, system configuration, peripheral management, and data processing [15]. The modular design balances functional requirements with non-functional considerations while adhering to top-down architectural principles, ensuring system security and operational efficiency. Taking the acquisition module as an example, it processes raw Wi-Fi channel CSI information through steps illustrated in Figure 3. This information is then transmitted to the preprocessing module for structured data parsing, signal processing, and subsequent processing before being fed into downstream modules.

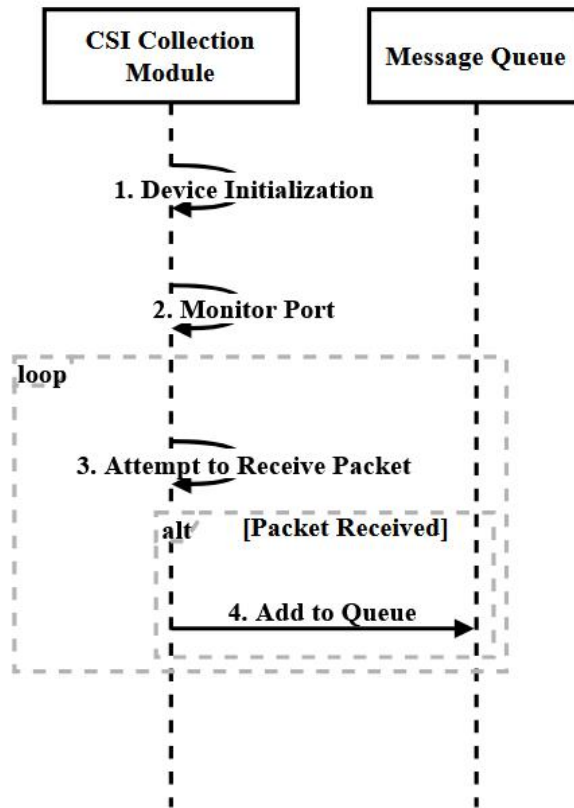


Figure 3 Schematic Diagram of CSI Acquisition Module

The system module operates as an independent process, which monitors UDP ports to retrieve CSI data encapsulated in UDP packets, thereby enhancing system responsiveness. The CSI model adopts non-blocking IO design to ensure asynchronous communication between the message queue and other modules, reducing coupling between components and preventing operational failures or delays during data acquisition from affecting subsequent processing.

3. Results

To evaluate the system architecture, it is essential to first understand the software and hardware environment of the evaluation program, as detailed in Tables 1 and 2:

Table 1 System Software Equipment Overview

Device Role	Device Model	CPU	Memory	Storage	Operating System
Transmitter	Raspberry Pi 4B	BCM2711@1.5GHz	4GB	32GB	Raspberry Pi OS 5.10
Receiver	Raspberry Pi 4B	BCM2711@1.5GHz	4GB	32GB	Raspberry Pi OS 5.10
Gateway	TPLINK TL-SF1016D	N/A	N/A	N/A	N/A
Control	MacBook Pro	Intel Core	16GB		macOS 13.1

Terminal and Other Devices		i7@2.6GHz			
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Table 2 Introduction of system hardware equipment

Category	Content and Version
Operating System	Raspberry Pi OS Lite (Kernel 5.10)
Programming Language	Python 3.8, C99, ECMA 2018
Software Framework	Nexmon 896805, Nexmon CSI 672cd2, Prometheus 2.37.5, Vue 2.6.10
Compilation Tools	make 3.8.1, gcc 12.2
Terminal Tools	tcpdump, xd
Browser	Chrome 109, Safari 16.2

With the support of the above-mentioned hardware, the core module functions are tested and analyzed. Among them, the test results of the Wi-Fi frame transmission function prove that the transmitting end can send messages at a fixed frequency. The actual transmission frequency is 500 messages per second, and the packet loss rate is 7.4%. The test results of the collection function prove that the collected data will be encapsulated into messages and sent to the port. Commands can be used to obtain the usage protocol on the interface, all messages of the destination port, and stored in the corresponding files. Moreover, the receiving end can normally collect the data of the Wi-Fi channel. The test results of the motion detection function prove that this module can continuously process the preprocessed data stream to find the starting position of the gesture action and then extract the complete gesture action data. The actual test position is relatively accurate, and the extracted gesture action data segment can contain complete gesture action data, meeting the expected requirements. The test results of the gesture recognition function show that the data set obtained in this study contains four actions and 4,800 samples. Before training the model, 200 samples were drawn from each action as the test set. After the model training was completed, 800 samples from the test set were used for evaluation. They could be processed successively by each module and then recognized and analyzed by the action recognition module. Moreover, the corresponding gestures could be correctly recognized, meeting the expected requirements.

Conclusion

In conclusion, in response to the information control requirements of smart home control systems in the new era, by adopting the design approach of Wi-Fi Internet and low-computing power platforms, gesture perception can be achieved through Wi-Fi signals. Compared with other technical methods, the system studied in this paper can significantly reduce the usage of system resources under the condition of similar accuracy rates, truly meeting the deployment requirements of low-computing power platforms.

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